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Title: Ice Shelf-ocean Interactions in High-resolution Global Simulations

Author(s):
Petersen, Mark Roger
Asay-Davis, Xylar Storm
Ringler, Todd Darwin
Hoffman, Matthew James
Price, Stephen F. Dr
Van Roekel, Luke
Wolfram, Phillip Justin Jr.
Comeau, Darin Scott
Wolfe, Jonathan David

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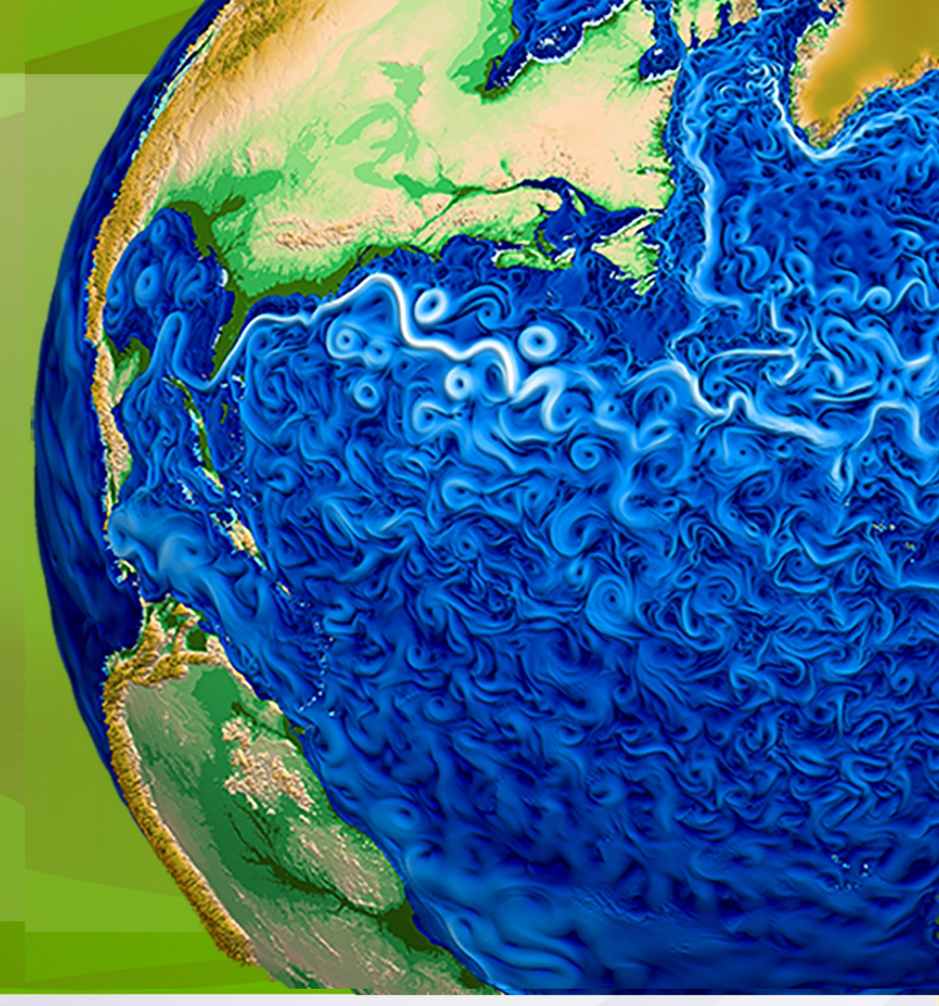
Ice Shelf-ocean Interactions in High-resolution Global Simulations I



Mark Petersen, Xylar Asay-Davis, Darin Comeau, Matthew Hoffman, Stephen Price, Todd Ringler, Adrian Turner, Luke Van Roekel, Phillip Wolfram

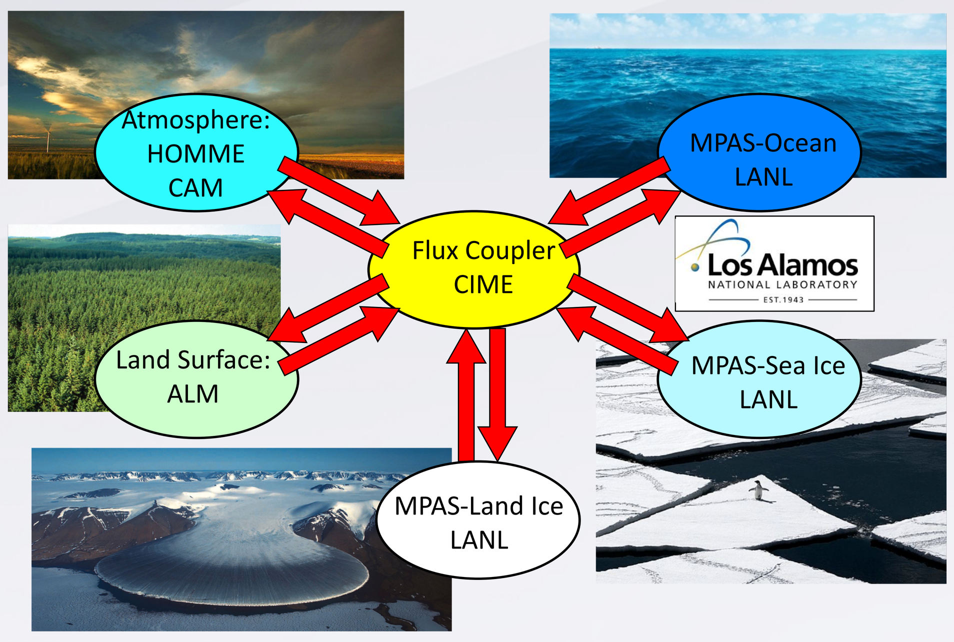
Los Alamos National Laboratory, U.S. Department of Energy

Abstract

Please also see companion talk:
250 - Ice Shelf-ocean Interactions in High-resolution, Global Simulations Part II, Stephen Price, B Parsenn, 21.06.2018, 9:00-9:15

The ability to include ocean cavities below ice shelves is a new feature of the U.S. Department of Energy's Energy Exascale Earth System Model (E3SM). This capability is critical for projecting Antarctica's potential future contributions to global sea level, which is one of E3SM's primary science drivers. E3SM is a coupled climate model with variable-resolution components, which allows global simulations to include enhanced-resolution regions below ice shelves. The ocean, sea ice, and land ice components use the Model for Prediction Across Scales (MPAS) framework for unstructured horizontal meshes based on Voronoi Tessellations.

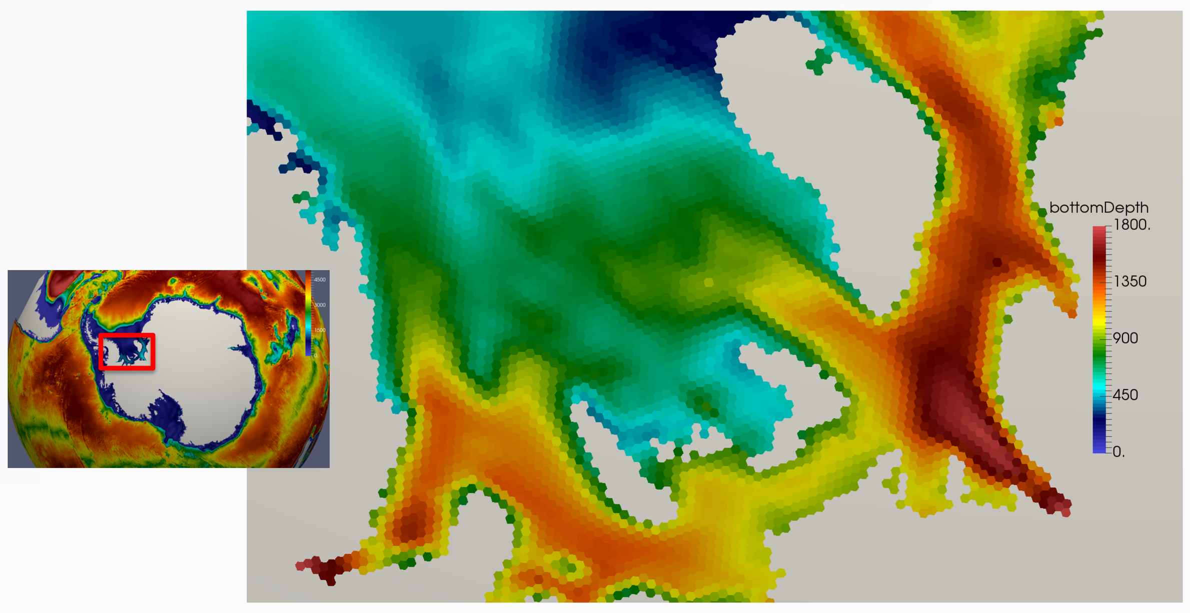
Energy Exascale Earth System Model



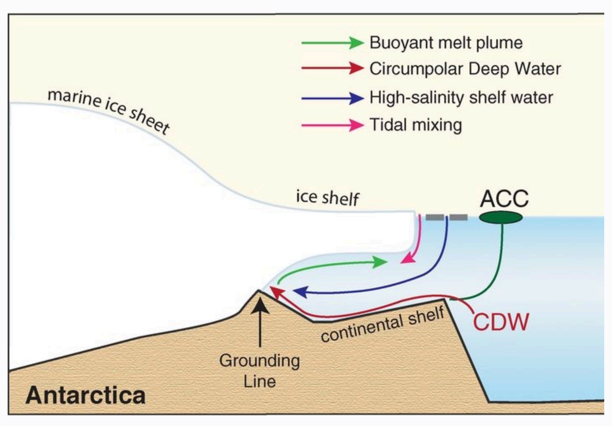
Global E3SM simulations were conducted in two configurations: low resolution, where horizontal grid cell size varies from 60 km at mid-latitude to 30 km at high latitudes and below ice shelves (EC60to30); and high resolution, where grid cells scale with the Rossby radius of deformation from 30 km at the equator to 10 km at high latitudes and below ice shelves (RRS30to10). Simulations include active ocean and sea ice components (Petersen et al., 2018; Turner et al,. 2018) with data (based on observed) atmospheric forcing and run-off from the Coordinated Ocean Research Experiments II (CORE-II) reanalysis (Large and Yeager, 2009). The ice shelf extent and depression are from observations (Fretwell et al., 2013) and remain static for the simulation. Basal melt rates are based on the model-simulated ocean temperature and salinity in the boundary layer at the base of the ice shelf (Holland and Jenkins, 1999).

MPAS-Ocean

The Model for Prediction Across Scales (MPAS) is a software framework for the development of climate model components on unstructured grids. MPAS variable density grids are particularly well suited to regional climate simulations, and placing high resolution in regions of particular interest.



Mesh for simulations, using 10 km grid cells, showing bathymetry below the Filchner-Ronne ice shelf.



Waters from the Antarctic continental shelf flow into the ocean cavities below ice shelves, melting the ice and increasing in buoyancy because of the influx of freshwater. The meltwater plume then ascends the ice-shelf base to the open ocean where it affects regional ocean properties.

Results

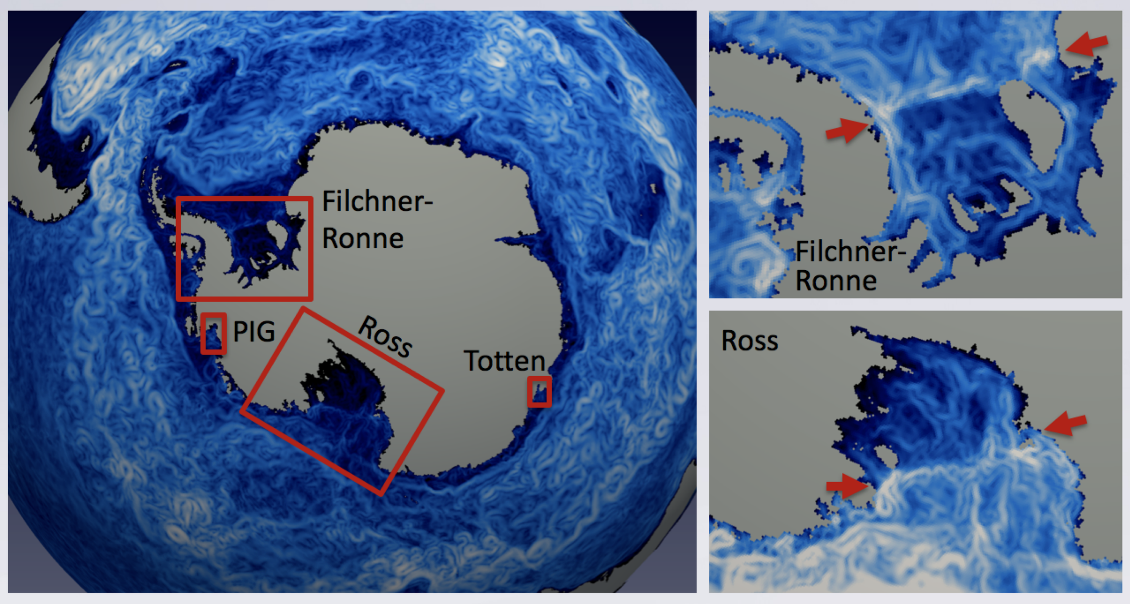


Figure 1. Instantaneous column-integrated ocean speed for the high-resolution simulation shows significant eddy activity throughout the Southern Ocean. Right panels reveal currents near and below the Filchner-Ronne and Ross ice shelves, where the shelf edge is denoted by arrows. White currents indicate column-integrated speeds of 500-2000 m2/s on left panel and 30-100 m2/s for right panels. Red boxes show locations of the two largest shelves, as well as for Pine Island Glacier (PIG) and Totten Glacier (for reference to Figure 4).

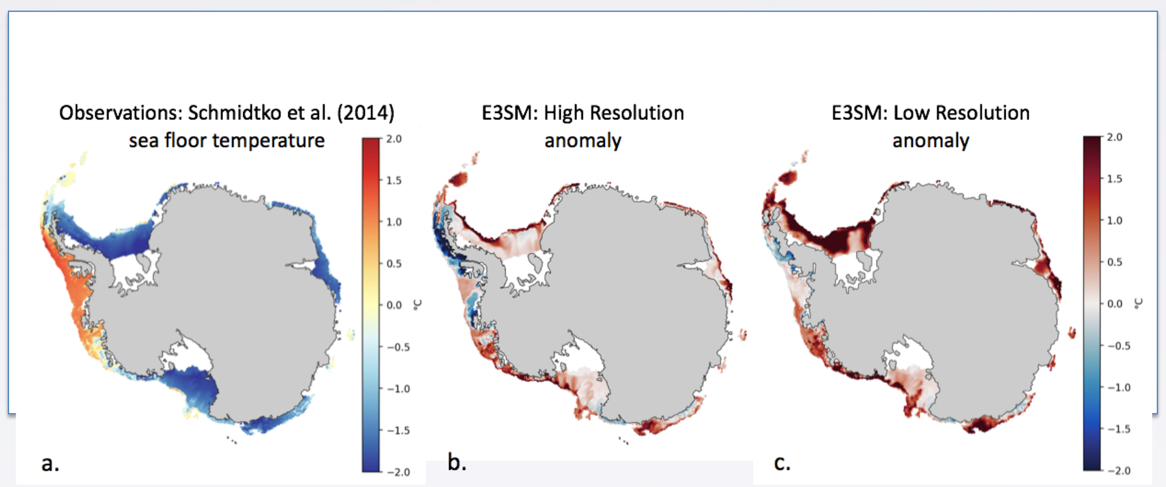


Figure 2. Sea floor temperature from observations (Schmidtko et al. 2014) (a). The temperature anomaly (model minus observations) from E3SM high-resolution (b) and low-resolution (c) simulations, averaged over ten years. At high resolution, warm biases are smaller in magnitude and geographic distribution.

Region:	Antarctica	West Antarctica	Peninsula	East Antarctica	Filchner-Ronne
Low Resolution	1.34	1.34	1.45	1.15	1.56
High Resolution	0.88	0.87	0.99	0.61	0.26

Table 1. Root-mean-square bias in seafloor temperature (°C), averaged over each region and over 20 simulated years. Bias is computed relative to observations (Schmidtko et al. 2014) as shown in Figure 2. Stepping from low to high resolution reduces the bias by 0.5-0.7 C.

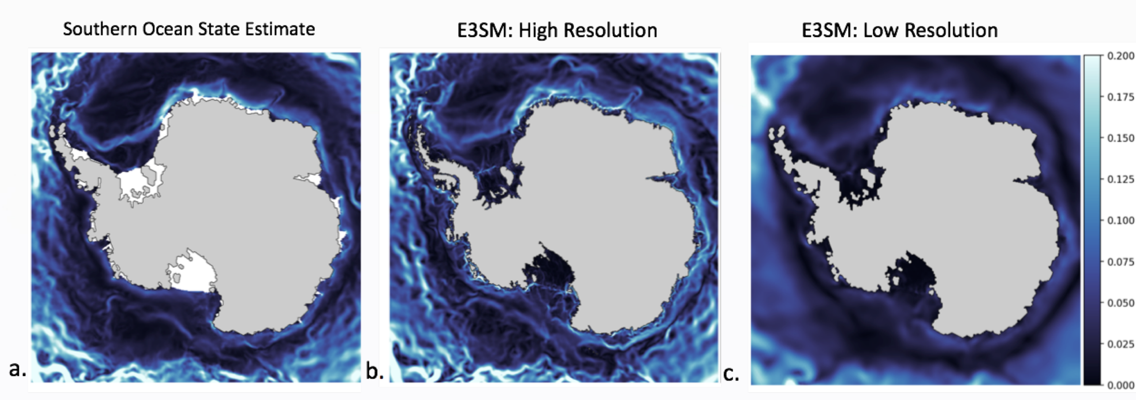


Figure 3. Sea surface velocity magnitude from the Southern Ocean State Estimate (Mazloff et al., 2010), based on observations (a), E3SM high resolution (b) and low resolution (c) simulations, averaged over ten years. High-resolution simulations produce eddy activity and currents (critical for mediating the flow of warm waters into ice-shelf cavities) at scales similar to SOSE, while these features are largely absent at low resolution.

Ocean model improvements that were needed for sub ice-shelf ocean simulations:

1. Tilted ocean layers (ALE grid) that slope down below the ice shelf (Petersen et al. 2015).
2. New pressure gradient formulation for tilted layers.
3. New initialization procedure for stable ice pressure-ice draft balance.
4. Land ice melt fluxes.

Results

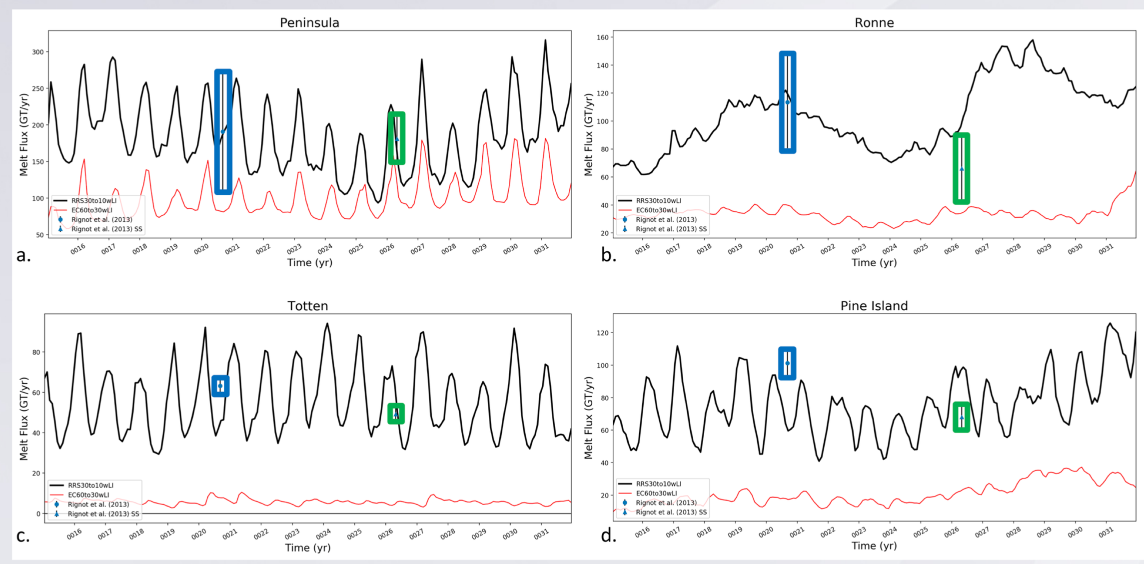


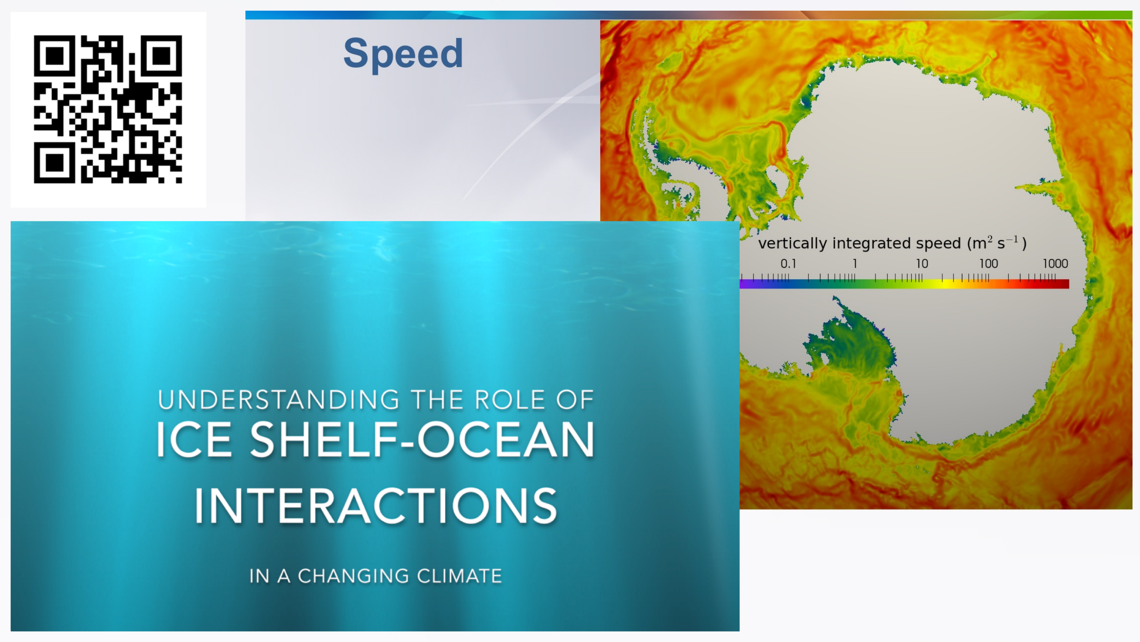
Figure 4. Melt rates, averaged over specific ice shelves or regions of Antarctica. High-resolution (black) and low-resolution (red) simulations are shown for 15 years. Time-averaged observations from Rignot et al. (2013) estimate non-steady state melt rates (i.e., observed, blue boxes) and steady-state melt rates (i.e., in the absence of observed ice shelf thinning, green boxes), where horizontal positions of boxes is arbitrary. In most locations, high-resolution simulations are closer to observations than the low-resolution results.

Future Work

- Creation of global mesh with enhanced resolution in Southern Ocean and highly enhanced in ice shelf regions.
- Further testing with active atmosphere
- In the long term, transition to dynamic ice shelves, moving grounding line, and coupling to land ice. This requires higher order pressure gradient in ocean, and wetting and drying of cells.

Documentary Video

Please see our five-minute video. Scan to view:



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E3SM Energy Exascale Earth System Model

For additional information, contact:

Mark R. Petersen
Research Scientist

Los Alamos National Laboratory
(505) 500-2739
mpetersen@lanl.gov

e3sm.org

Los Alamos NATIONAL LABORATORY EST.1943

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